SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

AD-A203 639

DTIC FILE COPY

DTIC ELECTE FEB 0 9 1989 S D

1a.	1b. RESTRICTIVE MARKINGS
2a	3. DISTRIBUTION/AVAILABILITY OF REPORT: Unrestricted
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S): RF-447230	5. MONITORING ORGANIZATION REPORT NUMBER(S): AFOSR-TR- 89-0053
6a. NAME OF PERFORMING ORGANIZATION: Department of Physics, The City College of N. Y. — 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION: AFOSR/NE
6c. ADDRESS (City, State, and ZIP Code)	7b. ADDRESS (City, State, and ZIP Code): Building 410, Bolling AFB DC 20332-6448
8a. NAME OF FUNDING/SPONSORING ORGANIZATION: Dr. G. Witt — 8b OFFICE SYMBOL (If applicable): NE	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: AFOSR-86-0031
8c. ADDRESS (City, State, and ZIP Code): Building 410, Bolling AFB DC 20332-6448	10. SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO. 61102F; PROJECT NO. 2305; TASK NO C1; WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)

Ultrafast Physics in Microstructure and Alloy Systems

12. PERSONAL AUTHOR(S)

Alfano, Robert

13a. TYPE OF REPORT	13b TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
~~Scientific~~ ANNUAL	FROM 12/1/87 TO 11/30/88	1/12/88	

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Quantum Wells

We have continued to employ picosecond and femtosecond techniques to investigate ultrafast physics in semiconductor bulk and microstructures. We have (i) determined exciton dissociation time by ionized carbon acceptors in GaAs QWs; (ii) proposed and demonstrated a new optical approach to measure directly momentum relaxation times which are related to electron mobilities in QWs; (iii) determined intervalley scattering in GaAs bulk and double-barrier tunneling structures experimentally and theoretically; (iv) determined X_6-Γ_6 scattering time of 0.5 ps in GaAs by picosecond IR absorption spectroscopy; and (v) observed stimulated excitonic emission in spherical (dot) quantum wells under picosecond UV excitation at room temperature.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL: ~~R. R. Alfano~~ Witt	22b. TELEPHONE (Include Area Code): (202) 767-4931 — 22c. OFFICE SYMBOL: NE

DD Form 1473, JUN 86 — Previous editions are obsolete. — SECURITY CLASSIFICATION OF THIS PAGE

(1)

AFOSR-TR- 89-0053

Annual Progress Report on Ultrafast Physics in Semiconductor Microstructures

to

DTIC COPY INSPECTED 1

AFOSR, Dr. G. Witt, Program Manager

Identification Number: AFOSR-86-0031

Research Foundation Number: 447230

Accesion For	
NTIS CRA&I	☑
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution /	
Availability Codes	
Dist	Avail and / or Special
A-1	

from

Robert R. Alfano, Distinguished Professor

Kai Shum, Assistant Professor

The City College of New York

January 12, 1989

89 2 8 033

Significant progress has been achieved under grant AFOSR-86-0031 to understand the physics underlying ultrafast transient phenomena that occurs in the semiconductor microstructures. This research is essential for making the necessary advances to help develop the future generation of ultrafast microelectronic devices.

Microstructure samples have been obtained primarily from H. Morkoc of University of Illinois, M. Niigaki of Hamamatsu Photonic KK, Rick Bertaska of McDonnel Douglas, Emil Koteles of GTE, and M. G. Spencer of Howard University.

Our key accomplishments were:

1. to determine the picosecond dynamics of exciton dissociation by ionized carbon acceptors in GaAs quantum wells.

2. to develop a contactless ultrafast optical approach to determine electron mobility in GaAs quantum well structures.

3. to determine Γ-X mixing effects on the lifetime of electrons in resonant states of GaAs/AlGaAs double-barrier tunneling structures.

4. to measure the changes of optical band gap properties in GaAs bulk and microstructures under picosecond-shock-wave excitation.

5. to measure intervalley X_6-Γ_6 scattering time in GaAs by picosecond pump-probe infrared absorption spectroscopy.

6. to measure L-Γ intervalley scattering rates in GaAs by femtosecond time-resolved four-wave mixing spectroscopy.

7. to observe stimulated excitonic emission from spherical CdSSe quantum wells under picosecond UV excitation.

The following report summarizes our major accomplishments in seven areas on GaAs semiconductor microstructures and bulk and on CdSSe microstructures using femtosecond and picosecond laser spectroscopy.

1. Picosecond dynamics of exciton dissociation by ionized carbon acceptors in GaAs quantum wells

It is most important to study the dynamics of formation, dissociation, and annihilation of quasi two dimensional (2D) excitons in undoped quantum well (QW) structures since many linear and nonlinear optical effects are associated with them.[1] Previous studies[2] have been focused on the determining of the dissociation rate of excitons into free electron-hole pairs, induced by the presence of high density of free carriers (screening effects) or by energetic phonons (thermal ionization). An exciton ionization time of 300 fs into free e-h pair was found in a multiple QW structure at room temperature.[3]

We have experimentally studied the dynamics of quasi 2D exciton dissociation by ionized C_{As} acceptors in unintentionally doped GaAs multiple QWs using time-resolved photoluminescence spectroscopy, which is most important for ultrafast device fabrication. Picosecond time-resolved photoluminescence

experiments demonstrate excitons can be dissociated by ionized carbon acceptors in a 55-Å GaAs multiple-quantum-well structure. A dissociation time is found to be ~ 250 ps and independent of temperature below 80 K. It takes about 20 exciton-phonon collisions for an exciton before being dissociated into free electron-hole pair.

This work was submitted to Phys. Rev. B (Rapid Communication) for publication.

2. A picosecond new optical approach to measure electron mobility in GaAs quantum well structures

The importance of the study of electron mobility in quasi two-dimensional (2D) GaAs-AlGaAs quantum well (QW) structures is well recognized. Following the Esaki and Tsu's idea of modulation doping,[4] most of experimental work by *electrical measurements* on the subject of quasi 2D electron transport in GaAs has beening devoted to increase electron mobility by controlling interface quality, background impurity, and electron density by adjusting the density of doping impurity in AlGaAs as well as the spacing between mobile electrons and ionized donors. Since 1983, the value of 4 K electron mobility in modulation doped heterostructures seems to be saturated around $2 \sim 3 \times 10^6$ cm^2/Vs These mobilities translates into average scattering time τ_μ (determined by $\mu = e\tau_\mu/m^*$) of 76 ~ 114 ps and mean free path of several micrometers for an elastic event to occur.

There has been no report on the direct *optical measurement* of momentum relaxation times which are related to electron mobility. Substantive picosecond time domain measurement is important because it supplements the information

about electron transport dynamics obtained from Hall mobility measurements. Many years ago, using optical approaches, Alfano and Baird[5] were able to determine carrier density in semiconductors and Perkowitz[6] related the electron mobility in n-type GaAs by infrared absorption spectroscopy.

Using picosecond time-resolved photoluminescence arising from electron to neutral carbon acceptor transitions, we have succeeded to determine the electron mobility (average electron scattering times) in an unintentionally doped GaAs quantum well structure in a temperature range below 80 K. Average electron scattering times by piezoelectric acoustic phonons, by ionized carbon acceptors, and by longitudinal optical (LO) phonons were directly measured and found to be, respectively, 106 - 0.817T ps in the temperature range of 10 to 50 K, 15 ps for T < 50 K, and 40 ps in the temperature range of 55 to 80 K. According to the 4 K scattering time, the electron mobility in the undoped GaAs QWs is 32 larger than high-purity bulk GaAs often quoted in the literature,[7] and comparable to the highest mobility to date in modulation doped GaAs heterostructures. The enhancement of the electron mobility is attributed to the increase of the binding energies of carbon acceptors in the QWs.

This contactless optical approach of the determination of electron mobility can separate different scattering mechanisms in picosecond time domain. This approach also eliminates the parallel conducting channel problem for Hall measurement, which can cause serious errors in the measured mobility of two-dimensional electron gas. Furthermore, Hall mobilities are not identical to conductivity mobilities which have been shown to be equal to drift mobilities. The difference is a Hall ratio r which depends on magnetic field intensity and the mechanism of

electron scattering. Therefore, studies of the electron mobility will benifit greatly from this direct optical technique, particularly if it can be done *in situ*.

We plan to extend this new optical approach to determine the electron mobility in modulation doped GaAs quantum well structures and compare its values with Hall data.

Part of this work is submitted to Phys. Rev. B for publication.

3. Γ-X mixing effects on the lifetime of electrons in resonant states of GaAs/AlGaAs double-barrier tunneling structures

Resonant tunneling phenomena in semiconductor quantum well structures are well known. It is extremely important to fully exploit this phenomena because a fast transistor can be made by turning this tunneling on and off in different resonant states. Most of previous electrical and optical studies have focus on the electronic states in central Γ-valley. How and what extent the coupling between the Γ-valley quasi-bound state in GaAs well region and X-valley quasi-bound state in AlGaAs barrier region will affect the tunneling is not well understood.

We have carried out a theoretical study on the electron lifetime in double-barrier GaAs/AlAs structures by taking Γ-X mixing into account. Our results show that when Γ-like state is not degenerate with X-like state, the lifetime of Γ-like state is exponentially proportional to the thickness of AlGaAs barrier. However, for the case when the Γ-like state becomes degenerate with X-like state, the lifetime will have a dramatic change and can be several orders larger than that of

a pure Γ system.

We plan to perform femtosecond experiments in this area and test the theory. This work will have important impact on the practical use resonant tunneling high speed transistors.

The theoretical part of this work was submitted to Phys. Rev. B for publication.

4. picosecond-shock-wave excitation of GaAs bulk and microstructures

Our preliminary data on shock-wave studies in GaAs quantum wells has shown a most interesting effect. The energy lavel of a GaAs/AlGaAs quantum well structure is almost unaffected while bulk band-gap of GaAs is blue-shifted under the same picosecond-shock-wave excitation. We are currently investigating the origin of this effect and other dynamic changes of optical properties in GaAs microstructures under picosecond-shock-wave excitation by picosecond photoluminescence spectroscopy. This work will have important impact to shield shock waves from high speed circuits and devices.

5. Intervally X_6-Γ_6 scattering time in GaAs measured by picosecond pump-probe infrared absorption spectroscopy

Intervalley scattering times place a lower limit on the relaxation time of conduction band electrons which determine the ultrafast speed for electronic devices.

We have investigated for **the first time the direct dynamics** of electrons in the X_6 valley for a GaAs crystal by time resolved absorption spectroscopy. IR picosecond probe pulses were used to monitor the growth and decay of electron population in the X_6 valley subsequent to the excitation by a 527 nm pump pulse. The intervalley $X_6 \rightarrow \Gamma_6$ scattering time of 0.50 ± 0.35 ps was determined. The scattering crosssection for the $X_6 \rightarrow X_7$ transition was estimated to be 4.5×10^{-17} cm^2. This work is a most significant breakthrough and is being continued.

This work was submitted to Phys. Rev. Lett. for publication.

6. Γ-L Intervalley scattering rates in GaAs measured by femtosecond time-resolved four-wave mixing spectroscopy

To complement our work under #5 above, we have employed a three-pulse transient grating technique to study intervally transfer dynamics in highly photoexcited GaAs. The femtosecond four-wave mixing signal exhibits a two component relaxation of different magnitudes for various probe energies. The fast relaxation mechanism is due to electron in the L valleys scattering back to Γ valley. The effective transfer time for $L \rightarrow \Gamma$ was found to be ~ 2 ps.

This work was published in Appl. Phys. Lett. 53, 1065 (1988).

7. Stimulated excitonic emission from spherical CdSSe quantum wells under picosecond UV excitation

It is well known that conventional (carriers are confined in one dimension while other two dimensions are free) quantum well lasers not only have high efficiency but also have large range of tunability. One hope to fully make use of quantum well laser properties by confining carriers in two dimensions (quantum wire laser) and in three dimensions (quantum dot laser). If the host material is III-V semiconductor, laser emissions arise from electron-hole recombination. Since exciton binding energy is larger in II-VI semiconductor than that in III-V semiconductor, laser emissions may arise from excitonic annihilation which should possess much larger oscillator strength than electron-hole recombination if the host material is II-VI semiconductor.

We have observed stimulated excitonic emissions in CdSSe spherical (dot) quantum wells under picosecond UV excitation at room temperature.

This work will be submitted to Optics Letters for publication.

References:

(1) D. S. Chemla, S. Schmitt-Rink, and D. A. B. Miller, in *Nonlinear Optical Properties of Semiconductors*, edited by H. Haug (Academic, New York, 1988).

(2) N. Peyhambarian, H. M. Gibbs, and J. L. Jewell, A. Antonetti, A. Migus, D. Hulin and A. Mysyrowicz, Phys. Rev. Lett. 53, 2433 (1984).

(3) W. H. Knox, R. L. Fork, M. C. Downer, D. A. B. Miller, D. S. Chemla, C. V. Shank, A. C. Gossard, W. Wiegmann, Phys. Rev. Lett. 54, 1306 (1985).

(4) L. Esaki and R. Tsu, IBM Res. Rep., RC 2418, Mar. 1969.

(5) R. R. Alfano and D. H. Baird, J. Appl. Phys. 39, 2931 (1968).

(6) S. Perkowitz, J. Appl. Phys. 40, 3751 (1969).

(7) C. M. Wolfe, G. E. Stillman, and W. T. Lindley, J. App. Phys. 41, 3088 (1970).

List of Participating Scientific Personnel

1. R. R. Alfano (Distinguished Professor)
2. Kai Shum (Assistant Professor)
3. K. S. Wong (Research Associate)
4. H. S. Chao (Graduate Student)
5. A. Katz (Graduate Student)
6. S. Lee (Graduate student)
7. W. B. Wang (Graduate Student)
8. Mi Yan (Graduate Student)
9. Sheryl Zhao (Graduate Student)

Students graduated under this program

1. A. Katz (12/88)
2. Kai Shum (08/87)
3. M. Junnarkar (05/86)